5. The intended subscriber unit recognizes the TXID it receives from the nearest cell transmitter (or strongest signal) and sends an acknowledgement (ACK) on the return link channel (see section II). All receive stations (Tx/Rx or Rx only) receive the ACK (if within communicating distance). The ACK includes the subscriber units unique ID and the TXID which it has received. The subscriber unit identification received on the return link channel also provides the approximate location of the calling (acknowledging) party.

6. The system controller upon receiving the ACK and receiver location information, sends a "GoTo" command to the subscriber unit which instructs the unit to switch to a specific channel at a given time and also the message length - concurrently the system controller forwards the message via telephone lines or satellite to the cell transmitter indicated by the subscriber unit as having the strongest signal.

7. Once the message is received by the cell transmitter, it is held in queue at the transmitter site for transmission at the appropriate time slot (see section II). The message is then transmitted on the data channel at its appointed time. PIMS does not dictate or endorse a particular format for message transmission on the data channel. The speed of data transmission on the data channel is determined by the subscriber units in PIMS due to its open data transmission protocol. In some cases this speed could be as high as 19.2 Kbps.

8. After each packet of the message has been successfully received, the subscriber unit sends back an acknowledgment (ACK). Otherwise an Automatic Repeat Request (ARQ) or a NACK, as appropriate, is transmitted on the return link channel.

This basically completes a typical transmission cycle. There can be some variations to the above described "typical" transmission cycle. For example, the message request can be generated by a subscriber unit. Communications can also be limited strictly between a landline entity and a subscriber unit within a building cell and or an office cell. The basic mechanism of establishing a data transmission link remains the same.

SECTION II - TECHNICAL DISCUSSION

To determine the feasibility of PIMS, SFA believes the proposed system can be broken down into four major design issues:

A. Cellular Concept and Frequency Reuse
B. System Coverage and Return Link
C. Adjacent Channel Interference
D. Signalling System and System Capacity

OUTSIDE (FREE SPACE) MODE

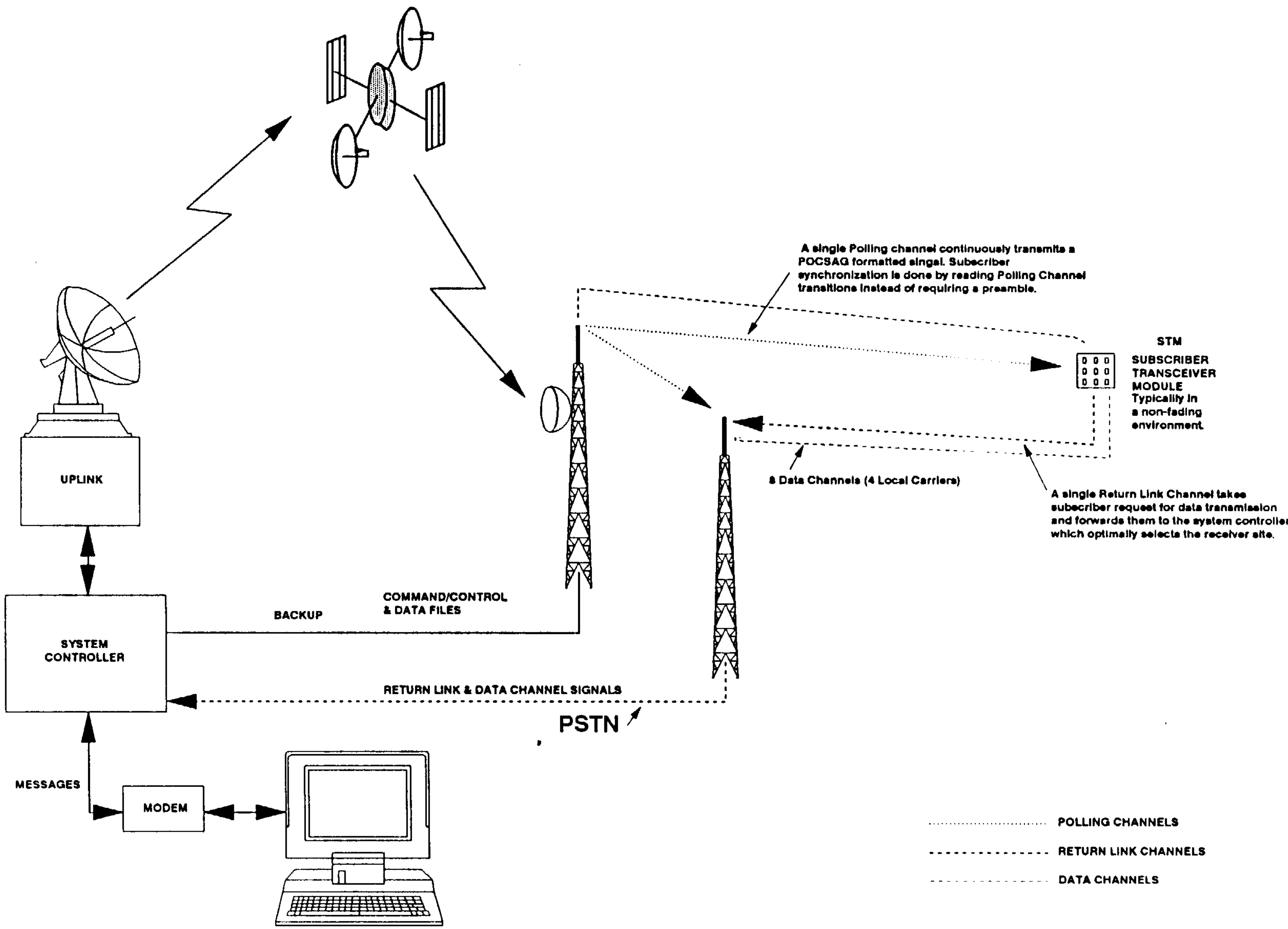


Figure 1

INBOUND MESSAGE/ACKNOWLEDGEMENT

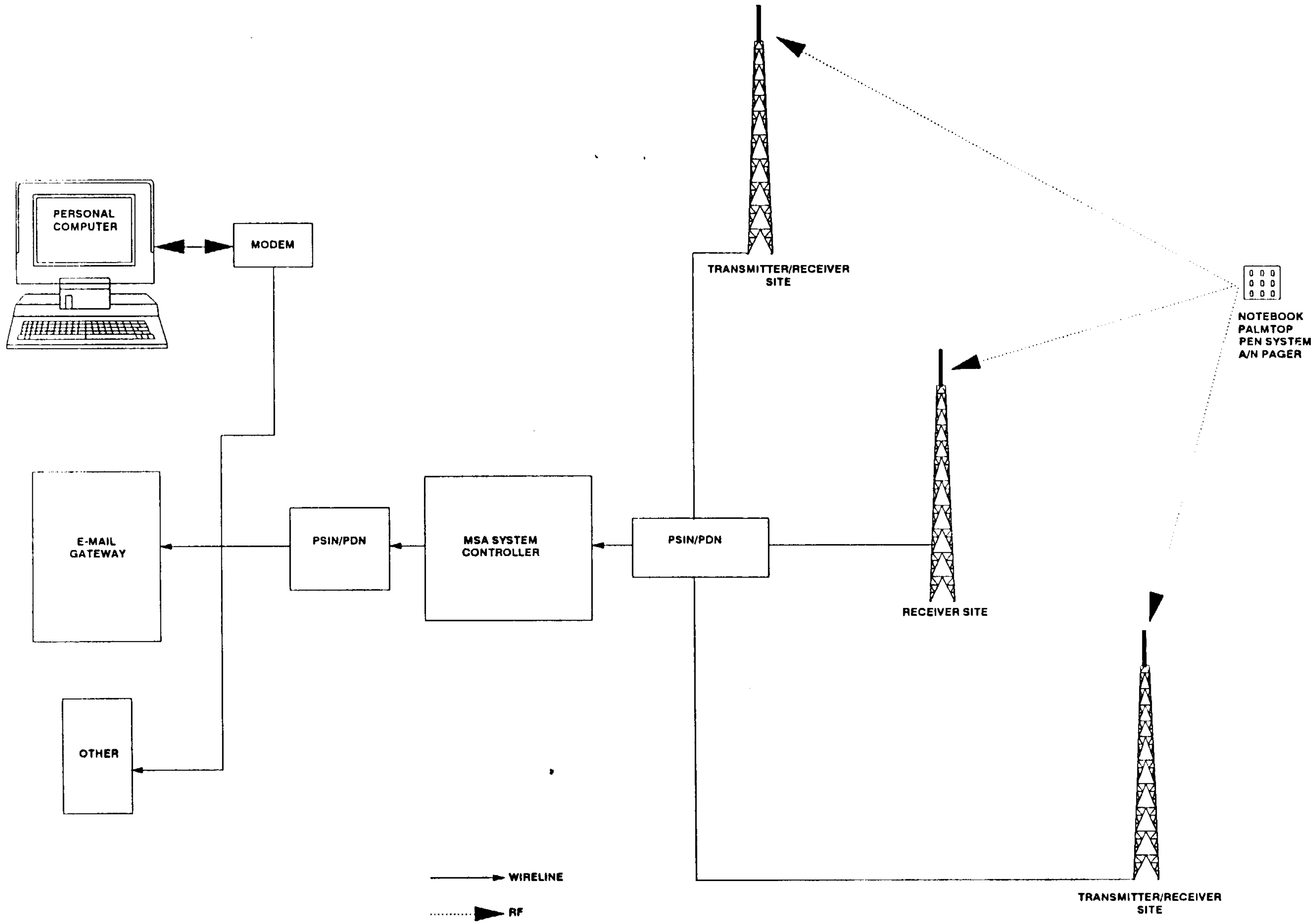


Figure 2

MESSAGE OUTBOUND TO SUBSCRIBER

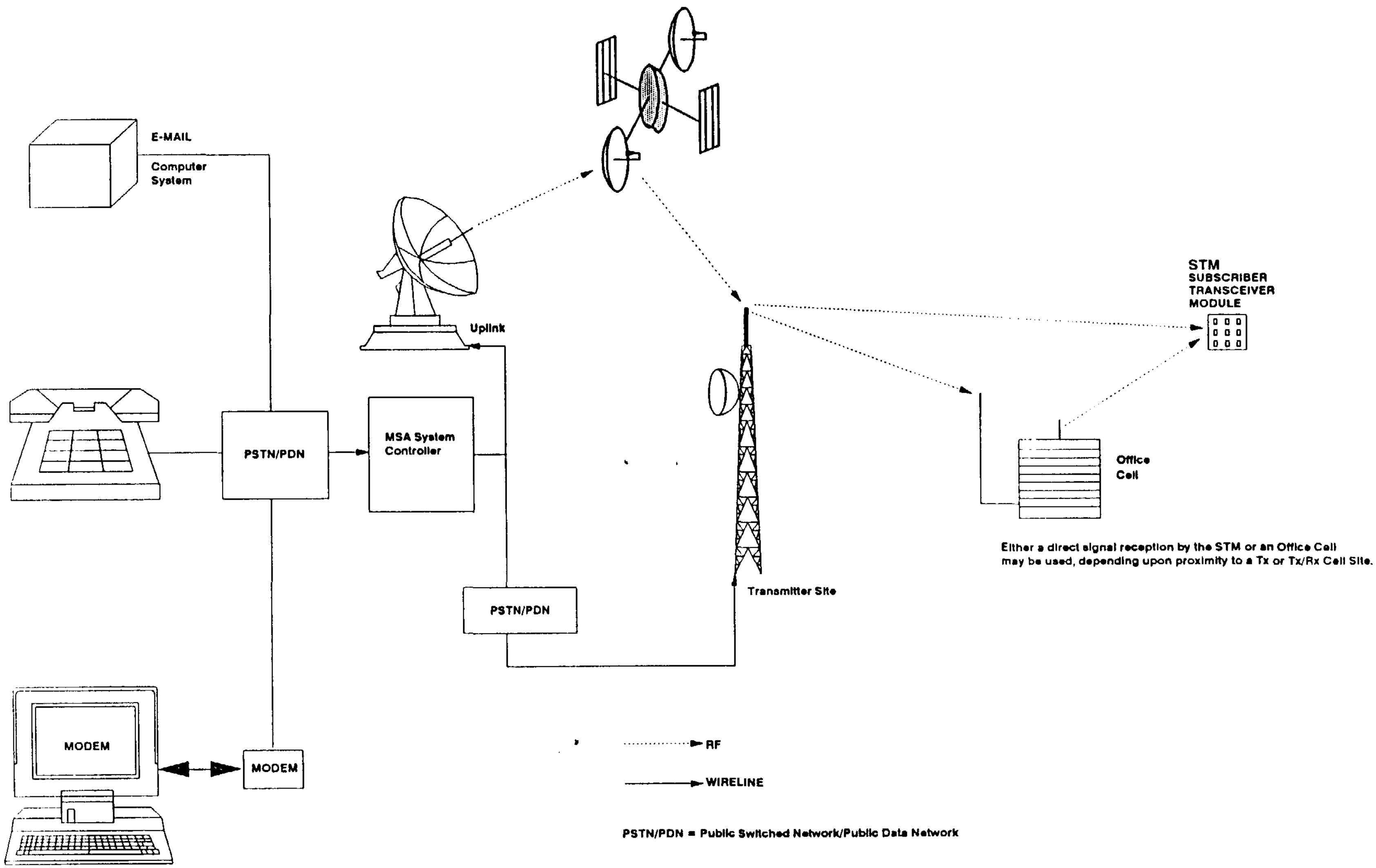
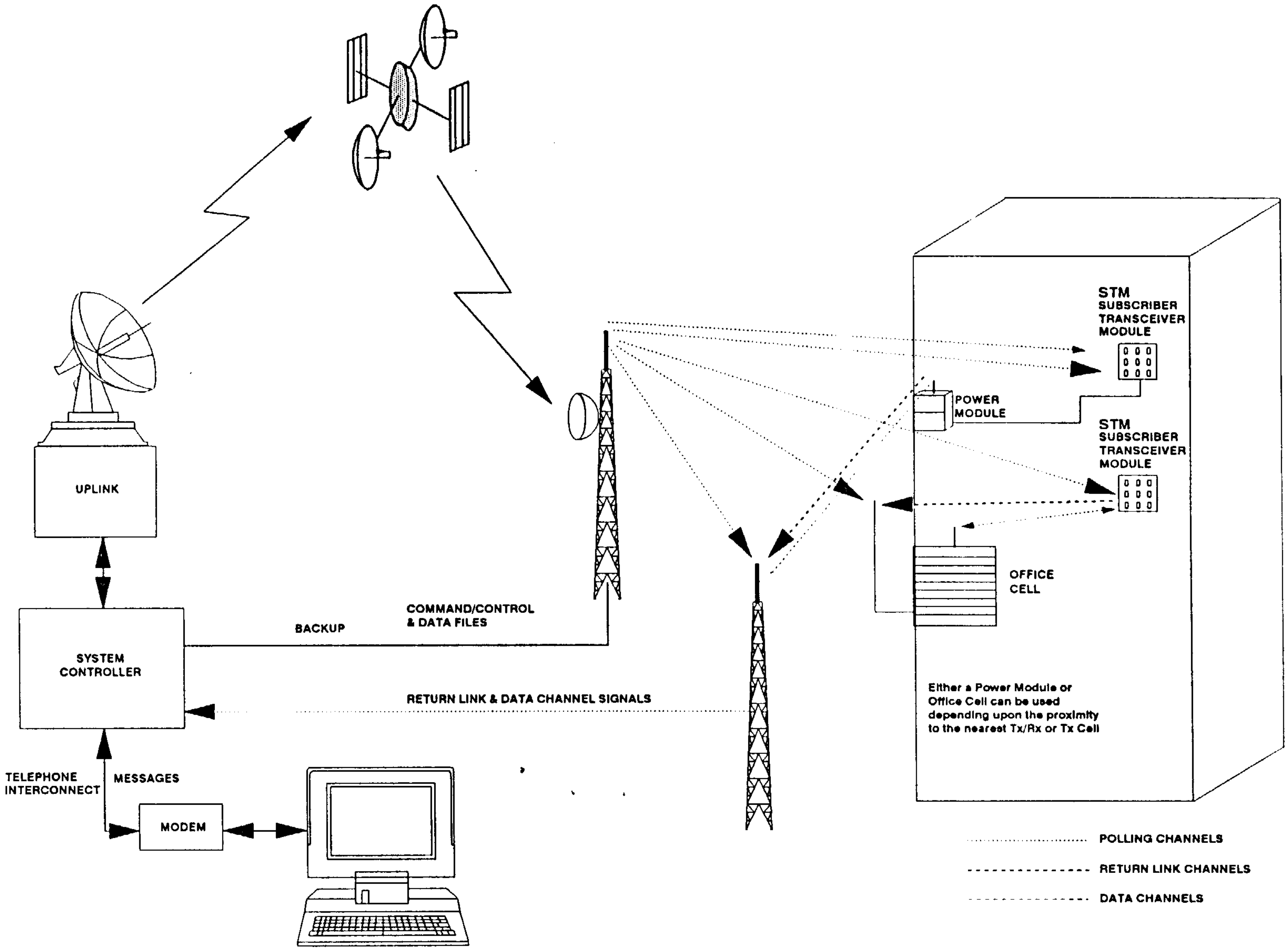


Figure 3

INBUILDING OPERATION MODES



Figue 4

CMS FUNCTIONAL BLOCK DIAGRAM

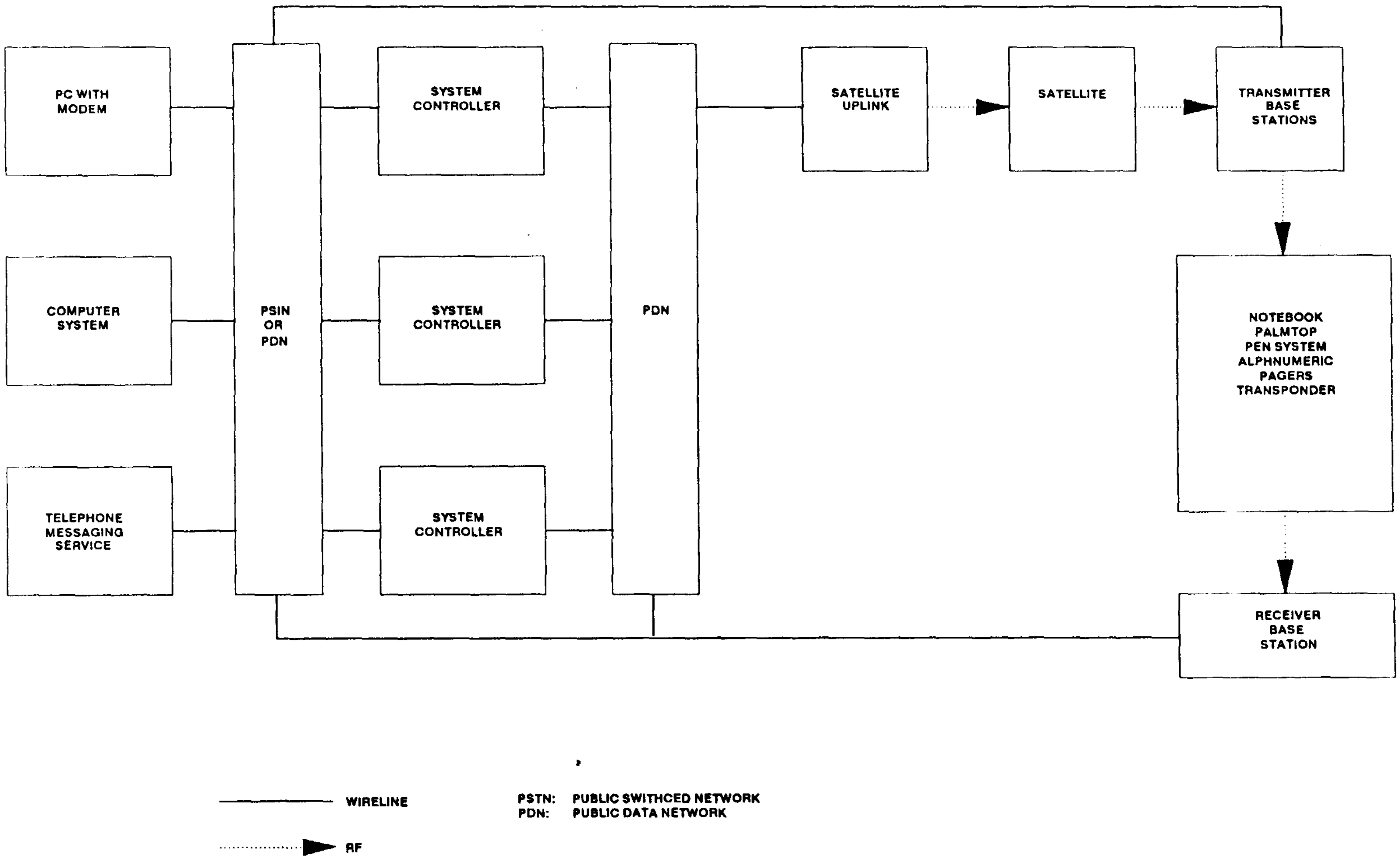


Figure 5

A. CELLULAR CONCEPT AND FREQUENCY REUSE

In its February 1992 Petition for Rulemaking PIMS proposes a digital 4 cell frequency reuse pattern.

> " The geographic cells would be designed in much the same way as typical cellular telephone cells are today, using a 4-cell reuse pattern, as depicted in exhibited II. These geographic , or 'free space' cells would utilize facilities and equipment comparable to conventional radio site ....." PageMart's Petition for Rulemaking, February 1992, page A4.

PageMart's 4 Cell Reuse Approach Not Only Feasible But Desirable

SFA has researched the 4 cell reuse pattern using both theoretical calculations and empirical and expert evidence from industry leaders such as Lee (Pactel) and Swerup/Uddenfeldt (Ericsson) [1, 2, 3, 4] and has therefore determined that PageMart's proposal based on 4 cell reuse is not only feasible, but desirable.

The use of a specific cellular frequency reuse pattern (3,4,7,12,19 or other) depends on several factors including:

- amount of available spectrum/total number of channels
- interference considerations
- system capacity/throughput considerations

Higher frequency reuse (e.g. 3/4 cell reuse design) is desirable for greater channel efficiency, but is considered more prone to inter-system interference. On the other hand, lower frequency reuse (e.g., 12/19 cell reuse design) is less spectrum efficient (requires more channels) but results in improved C/I interference protection. SFA concurs with the PIMS digital 4 cell reuse design because:

- it is operationally feasible,
- it will require less spectrum (channels). This is a critical requirement to conserve spectrum.
- Interference will be managed within recognized industry standard of 13 dB C/I ratio for digital systems. The following C/I ratios are considered acceptable under the given operating environment [1, page 428, 14.6.1, 2, 3, and 4]:

	Mobile (Raleigh, fading)	Portable (Rician, non-fading)
Analog C/I	18 dB	10 dB
Digital C/I	13 dB	5 dB

1. Theoretical Analysis

As PIMS is a digital, primarily portable (slow moving) system, it requires a C/I design criteria between 5 to 13 dB. The proposed PIMS system meets this criteria as shown in the following analysis:

$K = 4$ (4 cell reuse pattern) see [1], page 57

$q = D/R = \sqrt{3K}$ see [1], page 54

where q is the co-channel interference reduction factor, D is the distance between two co-channel cells, and R is the radius (constant) of each cell. For K = 4

$$D/R = \sqrt{12}$$

The number of co-channel cells in the first tier is equal to 6 (same as for a 7 cell reuse pattern) therefore the equation

$C/I = (D/R)^4/6$ see [1], page 58, E2.6-1

also remains valid for a 4 cell reuse pattern

$$C/I = (\sqrt{12})^4/6 = 24 = 13.8 \text{ dB}$$

Therefore even in a fast moving situations (signal fading), the 13.78 dB C/I ratio will be adequate.

2. Industry Experience

Dr. Lee of Pactel has demonstrated that edge-excited 3 cell and 4 cell reuse provides the required C/I ratios. In particular the 4 cell approach strikes the best balance between frequency reuse improvements (over 7 cell reuse) and maintaining proper C/I margins in microcell designs [10].

In addition Swerup/Uddenfeldt (Ericsson) concludes from its extensive testing of digital based systems that "when compared to 25 kHz analog systems, the required C/I ratio can be decreased by at least 5 dB ....." [3]

It is clear from the above discussion that a 4 cell design, will not only work but is <u>strongly desirable for PIMS</u> as it is spectrally more efficient and interference free.

B. SYSTEM COVERAGE AND RETURN LINK

One of the key elements in the baseline system for providing the personal information messaging service (PIMS) is,

> "A low-power subscriber transceiver unit, which provides the subscriber with a personal, low cost hand-held RF interface to the service and to the applications products that the subscriber uses" (PageMart Petition, page A3)

PIMS Return Link is Fully Functional In & Out of Buildings

As explained by PageMart, these transceiver units would have an ERP of 100 milliwatts to 1 watt. Office cells would include a 10 watt amplifier module that would compensate for attenuation in propagating through building walls (PageMart Petition page A13). Both the theoretical analysis (1) and empirical analysis (2) support the technical feasibility of this approach.

PageMart's system design for approximately balancing the number of return link receiver stations with the number of forward link transmitter stations can be shown to be a feasible system design (PageMart assumed that approximately 2 receive stations were needed for each transmitter base station) by both commonly used theoretical analysis as well as comparison with field proven, portable cellular telephone systems.

1. Theoretical Analysis

There are a number of propagation models[5] that can be used to calculate operating range depending on the particular environment under consideration. A commonly used model is one derived by Lee [1] for suburban areas as follows:

$$P_r = (P_t - 40) - 61.7 \text{ dBm} - 38.4\log_{10}r_1 + 20\log_{10}(h_1/100) + 10\log_{10}(h_2/10) + (G_t - 6) + G_m$$

where:
- P_r = receiver sensitivity in dBm
- P_t = transmitter output power in dBm
- r_1 = distance between the transmitter and receiver
- h_1 = antenna height at base (100 feet)
- h_2 = antenna height at remote unit (10 feet)
- G_t = transmit antenna gain in dB
- G_r = receiver antenna gain in dB

The maximum range from a remote unit to a base station can be calculated by substituting values in Lee's equation. Assuming a transceiver ERP of 100 milliwatts, a base station antenna gain of 10dB, and a base station receiver sensitivity of -116dBm, the maximum range can be calculated by,

$$-116 = (20 - 40) - 61.7 - 38.4\log_{10}r_1 + 20\log_{10}(100/100) + 10\log_{10}(10/10) + (0 - 6) + 10$$

$$38.4\log_{10}r_1 = 116 - 20 - 61.7 - 6 + 10 = 38.3$$

$$r_1 = 10^{38.3/38.4}$$
$$r_1 = 9.9 \text{ miles}$$

If 12dB to account for Rayleigh fading and an 8dB loss margin are added then,

$$r_1 = 10^{18.3/38.4}$$

$$r_1 = 3.0 \text{ miles.}$$

Similarly, if the transmitter ERP is one watt, r_1 is 5.5 miles.

If the transceiver is inside a building the 10 watt amplifier used with building cells would compensate for attenuation resulting from propagation through building walls. The 20 dB difference between an outside transceiver (100mW) and an inside building unit (10W) is more than adequate to compensate for any signal loss due to the building.

The range of a base station transmitter is computed in the same manner. Assuming a remote receiver sensitivity of -99 dBm, transmitter ERP of 500 watts, and using the same parameters as in the previous calculation, then

$$-99 = (57.0 - 40) - 61.7 - 38.4\log_{10}r_2 + 20\log_{10}(100/100) + 10\log_{10}(10/10) + (0 - 6) + 0$$

$$38.4\log_{10}r_2 = 99 + 57.0 - 40 - 61.7 - 6 = 48.3$$

$$r_2 = 10^{48.3/38.4}$$

$$r_2 = 18.1 \text{ miles}$$

Including 12dB for Rayleigh fading and an 8dB for loss margin,

$$r_2 = 10^{28.3/38.4}$$

$$r_2 = 5.5 \text{ miles}$$

Including 15dB for propagation loss through buildings would yield

$$r_2 = 10^{13.3/38.4}$$

$$r_2 = 2.2 \text{ miles}$$

Comparison of r_1 and r_2 demonstrates that the coverage range for the operating parameters assumed are comparable, and therefore in an operational configuration, the ratio of receivers to transmitters would be approximately equivalent and even in cases where higher base station transmitter power were used, there would not be more than two receivers per transmitter. Therefore the return link and forward link is approximately balanced resulting in fewer than two receiver sites per transmitter site.

As stated above the calculated ranges are for a very specific environment where the model is based on a combination of empirical measurements and theory. If the ranges are calculated using the plane earth model [5], and the parameters as above, r_1 = 14.2 and 25 miles for 100 milliwatts and 1 watt ERP respectively, and r_2 = 17.2 miles for 500 watts ERP. The plane earth model is a simplified model and, useful for assessing maximum range in flat rural areas.

To calculate ranges for other environments, models appropriate for the particular environment and range must be utilized. Those models require site specific information to produce accurate results [5,6] The sample range calculations demonstrate that the proposed system appears to be feasible.

2. Empirical Analysis (With Cellular Portable Phones)

The 100 milliwatt to 1 watt power level proposed for the subscriber unit is comparable to the 600 milliwatt power level standard in the cellular telephone industry for mobile transceivers. Those systems have been quite successful even with low cell density and operating in cars and many buildings. It is clear that if cellular systems operating at 600 milliwatts provide excellent service then the PIMS subscriber transceiver operating in free space has the potential to provide comparable service.

Although cellular units are rated at 600 milliwatts, their ERP is usually less because of poor antenna efficiency. Also, the signal transmitted from a cellular unit operating inside a high rise building is attenuated by as much as 25dB when propagating through the building wall. However, assuming a cellular ERP of 600 milliwatts and building attenuation of only 10dB, the equivalent power level outside the building would be 60 milliwatts. This level is less than the 100 milliwatt ERP of the PIMS portable units in operation outside the building. Moreover, in PIMS the office cell units inside the building use a 10 watt amplifier to compensate for signal attenuation in the building walls. The amplifier provides up to 20dB gain to the subscriber unit which is more than adequate to compensate for building wall attenuation. It follows, that based on a comparison with the cellular power levels, the PIMS power levels are more than adequate to provide a comparable level of service.

C. ADJACENT CHANNEL INTERFERENCE

Return Link Adjacent Channel Interference Controllable

Another system design consideration is adjacent channel interference in a base station receiver. Adjacent channel interference may be caused when a nearby transmitter produces a very large signal compared to the signal received from a remote subscriber unit when there is only 25kHz frequency separation between the two signals. To minimize adjacent channel interference the antennas and antenna installation must be designed to provide maximum isolation between the transmit and receive antennas. Additionally, adjacent channel interference can be avoided by using base station receivers with adequate selectivity, spurious response, and dynamic range specifications. If there are sites with severe interference levels, RF sampling and cancellation techniques could be utilized to eliminate the problem. Therefore, adjacent channel interference in the return link is controllable through conventional engineering design practices and would prevent adjacent channel interference from limiting PIMS system performance. Both (1) site engineering analysis and (2) industry experience support these conclusions.

1. Site Engineering Analysis

The potential for adjacent channel interference can be quantified by using typical values for the transmitter power, antenna gains, and receiver characteristics. The transmitter ERP used for calculating ranges was 500 watts. If the transmitter antenna has a gain of 10dB the power input to the antenna equates to 50 watts, or +47dBm. The base station receiver sensitivity used in the range calculations was -116dBm. In order for the transmitter not to create adjacent channel interference in the receiver the transmitter power must be attenuated by the ratio of the transmitter power to receiver sensitivity which is 47dBm plus 116dBm plus C/I requirement of 5B or 168dB.

Maximum dynamic range required in dB:

Tx Pwr(max)	47 dBm
Rx Sensitivity	-116 dBm
C/I	5 dB
Attenuation Requirement	168 dB

2. Industry Site Design Experience

The selectivity of the receiver provides at least 70dB of attenuation to the interfering signal. The radiation response of a typical 10dB gain antenna, such as a corner reflector, has an endfire response of less than -25dB, or -50dB for the receive antenna and transmit antenna combination. If the antennas are spaced 25 feet apart the free space spreading loss between the two is approximately 49dB. The following table shows site analysis.

Attenuation Budget:

Tx Antenna Pattern	25dB
Rx Antenna Pattern	25dB
Distance (25 ft.) Loss	49dB
Rx Selectivity	70dB
Total Available Attenuation:	169dB
Required Attenuation	168dB
Margin	1dB

Therefore, the total attenuation of the transmitter signal is then 70dB plus 50dB plus 49dB, or a total of 169dB which is greater than 168dB attenuation required. If at any particular site there is insufficient attenuation, signal cancellation circuitry can be utilized to provide an additional 10-20dB of attenuation.

D. SIGNALLING SYSTEM AND SYSTEM CAPACITY

PageMart in its notice of proposed rulemaking [pg. 14] states,

"Based on conservative assumptions of 6000 character average message size and an average of 2.5 messages per subscriber during a ten-hour busy period, the PIMS model indicates that over a hundred thousand subscribers per MSA (at 4800 bps) could be supported at a relatively small system size of 40 geographic cells, 40 building cells and 400 office cells."

SFA's analysis indicates that the stated capacity is not only feasible, but can actually be exceeded.

Polling Channel Can Support PIMS Subscriber Capacity Estimates

PageMart's proposed PIMS system includes a practical approach to the problem of determining which transmitter best serves the subscriber unit. The simulcast polling channel output of each transmitter is modulated with the transmitter identification at the POCSAG batch rate. Since the subscriber unit will lock onto the strongest signal automatically, by proven FM detection and capture principles the station identification can be recovered by processing the demodulated signal through a low-pass filter. As described in PageMart's proposal, a single bit of the transmitter identification would be transmitted during each POCSAG batch; the subscriber unit may pick out that bit while monitoring its assigned frame. Since the subscriber unit may identify only one bit of the station identification during each batch cycle, more than one batch cycle would be required (potentially three or four) to correctly identify the best serving transmitter. However, it is unlikely that the subscriber unit would be receiving messages during the initial startup period. Additionally, this transmitter identification method reduces the power consumption of the subscriber unit, as it may remain idle when its assigned frame is not being transmitted.

This transmitter identification method does not adversely affect the polling channel capacity, since the polling channel operates continuously. The polling channel capacity remains directly proportional to the achievable data rate of the subscriber transceiver unit. Given that manufacturers are currently developing the supporting technology for ERMES at a data rate of 6250 bps, using 4 FSK modulation instead of 2 FSK as conventional POCSAG, 4800 bps is well within the range of PageMart's lowest proposed data rate. <u>Therefore the Polling Channel can readily support PIMS subscriber capacity estimates</u>.

The POCSAG format (see Figure 6 & 7), originally developed for asynchronous pager applications, required that a preamble be periodically transmitted to allow for pager synchronization. PageMart's PIMS system, however, would allow the polling channel to operate continuously after initial startup procedures. Using a standard synchronization procedure, each subscriber unit would tune to the polling channel and perform a clock sync by watching transitions on the polling channel. Then a batch sync could easily be performed by matching the first codeword of each batch - the synchronization codeword. For this application, it would not be necessary for the polling channel to periodically transmit a preamble; all subscriber units would be able to sync up through this procedure.

Consequently, the polling channel capacity is directly proportional to the data rate using the POCSAG format. The POCSAG batch consists of one 32 bit synchronization codeword followed by eight frames, each consisting of two 32 bit codewords. The first bit of the codeword indicates whether that codeword is an address (0) or data (1). "Message codewords have 20 message bits, viz bit 2 to bit 21 inclusive and these are followed by the parity check bits" [8]. Thus, the POCSAG code efficiency is calculated by determining the available data bits per POCSAG batch, where there are 16 codewords consisting of 20 available data bits per batch, and each batch is 544 bits. Therefore the POCSAG Code efficiency is 58.8%.

Assuming a transceiver with 4800 bps capacity (considered feasible by Motorola, Inc. [9]) the polling channel capacity would be 2822 baud, or 70.6 frames per second. This translates to polling channel traffic of over 508,000 POCSAG codewords per hour. Since much polling channel traffic would consist of a radio location poll and a "GOTO Channel" command, the PIMS system could theoretically serve over 254,000 channel transactions per hour. Taking into account the 95% retransmission rate and a truly conservative message utilization rate of 80%, PIMS could still accommodate nearly 200,000 polling channel transactions per hour.

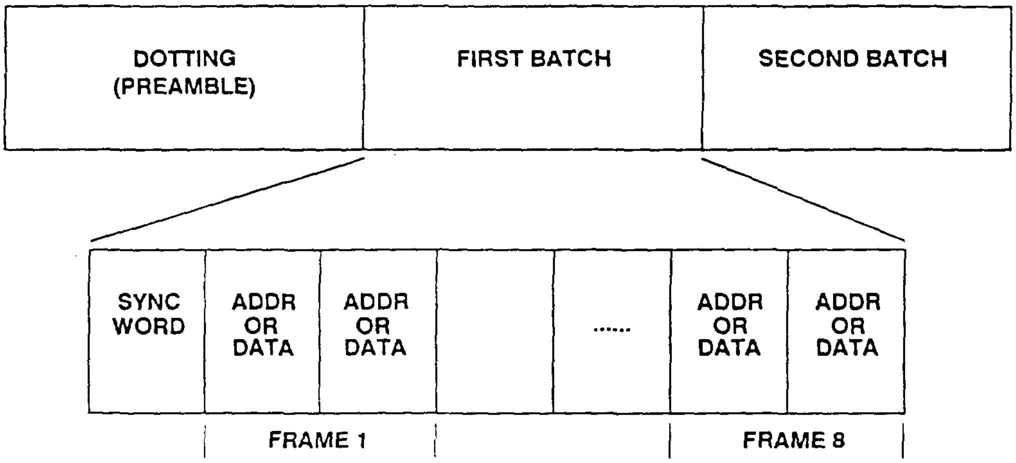


Figure: 6
Codewords are structured in batches which comprise a synchronization codeword followed by 8 frames, each containing 2 codewords. [8]

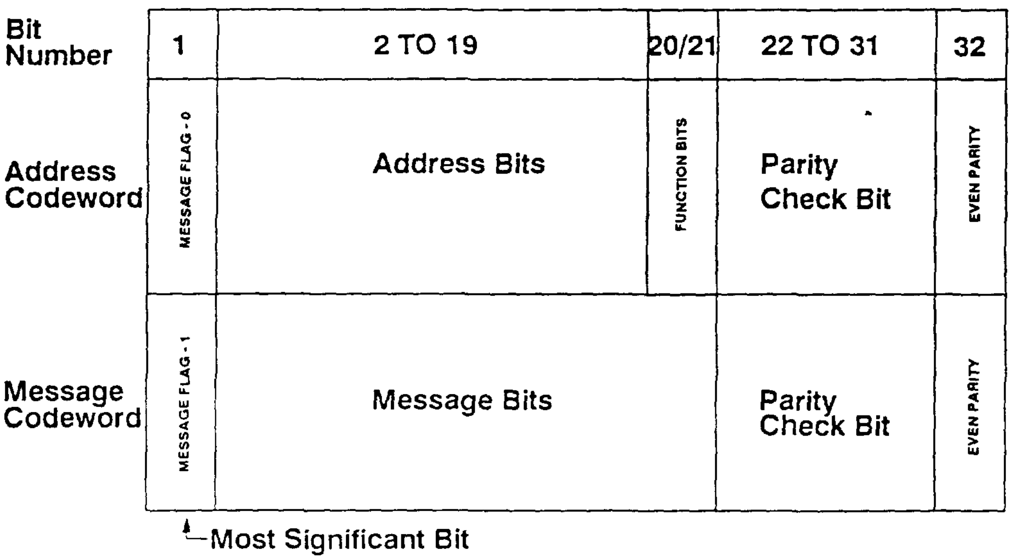


Figure: 7
A message codeword always starts with a 1 (the flag bit) and the whole message always follows directly after the address codeword. Message codewords have 20 message bits, viz bit 2 to bit 21 inclusive, and these are followed by the parity check bits. [8]

As the PIMS "GOTO Channel" codeword consists of 20 data bits, there is ample room to inform the subscriber unit not only of the channel on which it will receive data and during which time slots, but also how many packets of "2 to 5 POCSAG batches" it will be receiving.

Therefore, there is no need to use the polling channel to assign a data channel for each individual packet. The subscriber unit can stay on the same data channel until all predetermined packets are received, providing acknowledgement or requesting retransmission on the return link. Therefore, the polling channel capacity is the same as the number of channel transactions per hour, nearly 200,000.

Return Link Capacity Matched to Forward Polling Link

The PIMS Return Link Channel is the link from the subscriber units to the local receiver used to respond to the Polling Channel radiolocation or Data Channel Acknowledgements. After a radiolocation poll, the subscriber unit must indicate that it has received the poll and the best serving transmitter on the PIMS Return Link Channel. The subscriber unit responds to the radiolocation poll during the first word of its assigned frame one batch time later. Following each data packet transmission, the subscriber unit must acknowledge that the packet was received correctly or request retransmission. The frame during which the subscriber unit responds is dependent upon the frequency channel it had received data, not upon the subscriber unit's assigned frame. An ACK or ARQ is transmitted one batch time later during the second word of the frame corresponding to the data channel number. For example, a unit receiving data on channel three would ACK one batch time later in the second word of frame three; a unit receiving data on channel four would respond in the second word of frame four one batch time later. The nationwide carriers would have eight data channels requiring response; the POCSAG format consists of eight frames, allowing PageMart's PIMS system to fully utilize the spectrum. Since the unit responding to the radiolocation polls is using the first word of a given frame and a unit acknowledging data transmissions is responding during the second word of a given frame, there can be no collisions.

The subscriber unit in each situation above would have one entire codeword on the return link to inform the system controller of its disposition. The useable bits in the POCSAG format would allow the subscriber unit to indicate more than the best serving transmitter or which packet to retransmit; therefore, this format allows for additional features to be added by each carrier. Perhaps a subscriber would like to receive messages during non-peak hours or to place messages in a mail-box; this disposition may be stored in a data base or may be sent as a response to the radiolocation poll. The subscriber unit requesting retransmission may indicate which packet requires retransmission as well as additional information allowing each carrier to customize services.

The capacity of the return link channel is directly proportional to the data rate of the link. Assuming again a 4800 bps link, the return link channel can handle 70.6 POCSAG frames per second, resulting in over 508,000 Return Link Channel transactions per hour. Therefore the Return Link Channel can accommodate over 254,000 poll responses and over 254,000 data acknowledgements. The poll responses will not present a capacity problem for the return link, since the response takes only one codeword for each of the poll channel's two. The Return Link Channel, however, must also accommodate up to 254,000 data channel acknowledgements per hour.

In order to actually receive the maximum number of data channel acknowledgements, the local transmitter would have to be sending packets of length no longer than one frame on each of the eight data channel; this cannot occur with the PIMS system. Secondly, there can only be collisions if one local receiver is picking up acknowledgements from two subscriber units which have received messages on the same data channel -- an impossibility using the PIMS system. The local controller would indicate to the system controller, most likely via land lines, that all packets were received correctly (EOT) or that a particular packet should be retransmitted (ARQ). The system controller may allow for a 5% retransmission overhead when allocating data channel slots or may perform another Poll-GOTO for retransmission of errored packets only if necessary.

The subscriber unit also requests a time slot for subscriber originated messages on the return link by transmitting an RF burst during the second codeword of its assigned frame. The subscriber indicates the message length to be transmitted, the serving transmitter site identification, and the subscriber unit identification, or call sign per Pagemart proposal. The subscriber unit would indicate its transmission request at such time that there are no Data Channel acknowledgements being transmitted during that frame through an algorithmic procedure. The probability of collisions during a subscriber originated message request would be low, because it is expected that the majority of messages would not be subscriber originated. Secondly, since all subscribers are assigned one of eight possible frames, the probability of collisions is further reduced. It is not expected, therefore, that subscriber originated message requests would adversely affect the Return Link Channel capacity. Therefore, the return link capacity is effectively matched to the forward polling link.

System Capacity is Conservative

PageMart's proposed PIMS system incorporates the concept of a portable subscriber unit, not a mobile unit. In a portable subscriber unit system, subscribers primarily are stationary or nearly stationary while receiving messages[2]. This "pseudo stationary" position would most likely occur when in a building or office. PageMart's proposed PIMS system exploits these high traffic clusters by providing isolated office and building "microcells" within a geographic cell, further enhancing the degree of frequency reuse. PageMart's assumptions for calculating PIMS capacity are very conservative; SFA will use the following assumptions in our review of PIMS capability.

Assumptions

1) Average percentage of cells (geographic and building) containing messages per batch = 70%

   This is the industry accepted value for paging. PIMS is not simply a paging system, and this value should be larger in practice; however, SFA realizes the importance of not overestimating capabilities and will use 70%.

2) Average message utilization of each batch (geographic & building) = 80%

   Again this is the industry accepted value which SFA, Inc. will use.

3) Data channels per cell -

Geographic	- 8 channels
Building	- 6 channels
Office	- 1 channel

   These are the number of channels requested by PageMart.

4) Average utilization of office cells = every third building cell batch or 1/3 batch.

5) Proportion of batches involving geographic cells versus building and office cells = 1:1

   SFA believes that this ratio would more likely be 1:4 or 1:5. In order to perform a conservative estimated capacity, SFA will use 1:3.

6) Percentage of geographic cells that can transmit on a non-interfering basis during building cell transmissions = 50%

   Again, it is SFA opinion that properly organized building and geographical cells should be capable of transmitting on a non-interfering basis a much higher percentage of the time; therefore, this is an extremely conservative estimate. A more likely value would be 75%.

7) POCSAG Code Efficiency = 58%

   On a continuous basis, the POCSAG Code Efficiency is actually 58.8%.

8) Busy Hour Period Characteristics: a) 10 hours, b) 2.5 messages per subscriber, and c) 6,000 characters per message

9) Average re-transmission as a fraction of total batches = .95

10) Comparative simulcast system is 100% efficient or theoretical efficiency used for comparison

Equivalent Throughput Calculation (Relative to Simulcast)

Geographical Cell Batch =

(40 cells/4 cell re-use) X 8 channels X .7 X .8 = 44.8

Effective Channels

Building Cell / Office Cell and Non-Interfering Geographical Cell Batch =

(40 building cells X 6 channels X .7 X .8)
+ (30 geographical cells/4 cell re-use X 8 channels X .7 X.8)
+ (400 office cells X 1 channel X .7 X .8 X 1/3)
= 242.7 Effective Channels

Average Batch Throughput =

(44.8 X 1/4 + 242.7 X 3/4) X .95 = 183 Effective Channels, or stated differently has a 18.4 multiplier over a theoretical simulcast channel.

This translates to an Average Subscriber Capacity @ 4800 bps of over 153,000 subscribers. Thus, still using conservative estimates, SFA has calculated that the PIMS system could handle 40% more subscribers than PageMart had claimed. Therefore, PageMart's PIMS system capacity estimates are conservative as confirmed by SFA.

SECTION III - SYSTEM ARCHITECTURE AND TECHNOLOGY

System architecture used by PIMS is novel and is only distantly related to the current cellular telephone technology. The only common thread is that they both take advantage of frequency reuse.

1. PIMS is Fundamentally Different than Cellular Telephone

PageMart's approach to PIMS is fundamentally different than cellular telephone for a number of reasons:

1. PIMS signalling format is based on modified POCSAG and is broadcast wide area using two one-way channels. Signalling in Cellular is based on unique channels (21 all together) - one in each cell.

2. Subscriber units are not constantly locked on to signalling channel control data as in cellular, but communicate only when alerted or turned on by the polling channel. Even after being alerted, the subscriber units do not establish an interactive link on the signalling channel as done in cellular but do so only in bursts - only during actual transmission. At all other times the subscriber unit remains quiet. This conserves battery in the subscriber unit as is the case in pagers using the POCSAG system.

3. Transmitter Identification (TXID) information received by the subscriber unit is stored in the unit - and is then used in all future return transmissions to indicate its current choice of transmitter with which to communicate. This TXID is updated whenever a new TXID is received.

4. Signalling in PIMS is based on non-interactive packet switching whereas cellular signalling is based on circuit switching.

5. Similar to SMR, subscribers are assigned a home service area. This concept provides relief in system traffic by providing a priority knowledge (with high probability) of the location of the receiving unit and its coverage transmitter. The channel inefficiencies involved with simulcast broadcast are therefore significantly reduced by knowing the home MSA (or even building cell) with high probability before transmission.

6. PIMS signaling essentially requires 8 steps between the controller, base transmitter, and subscriber unit to complete an error free one way message transmission. As it is a non-interactive process, each step may involve delays of various length, depending on traffic load. In cellular, a complete land to mobile call requires 23 steps to set up and release a call [5], excluding any additional steps

required for handoff. (Each step can be defined as performing a unique function and consists of a varied number of bits or bytes depending on the function of each specific step.)

7. PIMS signaling utilizes a low cost network infrastructure that does not provide for hand-off. Lack of hand-off capability is not considered to be a problem since data bursts typically lasts for seconds, not minutes as in voice transmission. Any breaks in transmission can be rapidly and automatically completed using the new TXID that is captured by the subscriber unit. Cellular signaling is based on telephone signaling techniques with capability for hand-off and complex on-line transmission monitoring capabilities. The purpose and function of the two signaling mechanisms are completely different.

2. PIMS Uses Current Technology

The technical feasibility of PIMS is enhanced by its use of existing, commercial technology. Specific customization will be required to adapt current technology to the PIMS operating environment.

It is not necessary to list each subsystem or hardware component of PIMS and discuss its viability under the current state of the technology. Many of the components of PIMS have been around for a long time and are well known even to the general public. For example VSAT technology, POCSAG paging format, cellular frequency reuse, radiolocation, etc. are all working examples of PIMS technology. Yet PIMS is none of the above due to its unique operational design and blending of these technologies. SFA will highlight only those unique areas of PIMS which are dependent on modifications or enhanced version of existing technology, and will be covered in (a) Network Hardware, and (b) Data Transmission Devices.

a. Network Hardware

A custom system controller will be required. This could be done mostly through software modification/enhancement to an existing controller used in a packet switching network (store and forward type network).

Cell site base station will require programmable features and data storage devices. Current trunked radio technology, cellular, facsimile and scores of others are some examples of programmable transmission devices.

All other network hardware is commercially available.

b. Data Transmitting Devices

Two devices in the network will be transmitting data over the RF data channels. The cell site transmitter and the subscriber unit. The rate of data transmission over a 25 kHz channel directly affects the system capacity of PIMS. Current technology allows for up to 19.2 kbps. Some examples of data throughput are

- Ram Mobile Data has indicated that it achieves 8 kbps on a 12.5 kHz channel.
- Dataradio™ achieves 9.6 kbps on a 25 kHz channel.
- SFA laboratory tests have exceeded 4800 kbps of raw data on a 3 kHz bandwidth channel.
- Several Multiple Address Systems (MAS) such as Multipoint Networks and Comptech currently achieve 19.2 kbps in a 25 kHz bandwidth channel.
- Motorola's new InfoTac achieves both miniaturization and 4.8 kbps data transmission speed. Plans already call for upgrade to data packet transmission 19.2 kbps and interface to laptop and notebook computers.

In addition Motorola, Inc has indicated in their July 1992 letter to PageMart that the data speeds claimed by PIMS in notice of proposed rulemaking are achievable [9].

SECTION IV - CONCLUSION

Total system throughput is the landmark achievement of PIMS. Yet this would not be possible without strict interference management, using the proposed 4 cell design with embedded micro and pico cells and the use of POCSAG polling/return channel (8 frames = 16 words) and eight data channels. It is clear from the technical discussion in section II and III that system throughput will be achieved (even exceeded with hardware/software improvements) based on the following conclusions:

PIMS 4-Cell Reuse is not Only Feasible but Desirable

(1) Co-channel interference is carefully managed. The C/I ratio of 13.78 is sufficient for a digital based system in a fading environment. Prudent system design followed by detailed field testing will be of paramount significance. This is all achievable using good engineering practices. For example, PIMS utilizes managed power levels to alleviate inter-system interference. The technical discussion proves that

interference can be well managed with the 4 cell system design. Cell sectoring is used where higher traffic volume or unusual surroundings result in higher interference.

PIMS Return Link is Fully Functional In and Out of Buildings

(2) PIMS return link and forward link is approximately balanced resulting in fewer than two receiver sites per transmit site.

(3) Ten (10) watt wireless repeaters are used inside buildings to provide in-building coverage. Further, this will allow subscribers to be untethered in their work environment.

(4) Acknowledgment to data transmission takes place during the second word of the frame one batch later on the frame number corresponding to the channel number to avoid any collision. No problem should be encountered here.

(5) Response to a polling channel for radio location takes place during the first word of the assigned frame one batch later on the return channel to avoid any collision (POCSAG format). PIMS proposes such a mechanism.

Adjacent Channel Interference in the Return Link is Controllable Through Conventional Engineering Design Practices.

(6) Each system is planned around existing sources of interference by strategically placing transmit and receive sites away from adjacent channel interference sources. This can easily be achieved during initial system planning. There are hundreds of antenna sites available in large metropolitan areas. There is no reason why any potential source of interference cannot be altogether avoided by careful initial system planning.

PageMart's PIMS System Capacity Estimates are Conservative.

(7) Polling channel efficiency is not reduced due to periodic preamble requirements for synchronization as in conventional POCSAG paging. Subscriber unit synchronization in PIMS is done by reading the transitions taking place on the polling channel (each frame of POCSAG. This is critical - but a

fairly standard operational procedure. PIMS polling channel can readily support the proposed subscriber capacity.

(8) Return link capacity is effectively matched to the forward polling link using both works in each POCSAG frame - allowing radio locationing (TXID) and acknowledgment to take place. PIMS meets this requirement.

(9) Subscriber attempts for channel access takes place in those batch cycles set aside for that function. Given the expected traffic in the forward link direction random access attempts consumption of return link capacity is expected to be small. PIMS meets this requirement.

PIMS Capacity Can Grow Significantly Over Time.

(10) The primary users of the system are inside buildings that employ building or office cells. The use of building and office cells substantially increases system capacity.

(11) Data transmission is independent of any specific protocol or standard. As advances in higher data throughput are achieved via hardware/software improvements, PIMS system capacity will proportionally increase.

PageMart's "Cellular" Approach to PIMS is Fundamentally Different Than Cellular Telephone.

(12) Signalling in PIMS is non-interactive for packet system type architecture. This also results in low infrastructure cost. PIMS is different from conventional cellular telephone other than employing the principle of frequency reuse. (NOTE: PIMS does not employ hand-off capability being unnecessary for relatively short bursts of data as opposed to prolonged telephone conversations. Instead, if a data packet is not completed in a given cell retransmission, it automatically initiated through the polling and acquisition of a new TXID location process.)

The Technical Feasibility of PIMS is Confirmed by its Use of Existing Commercial Technology.

(13) Existing technology is used. PIMS meets this condition since no new high-speed coding design is proposed.

(14) Frequency reuse is employed rather than simply increasing data rate.

(15) Transceiver power levels range from 100m watt to 1 watt, a low power solution of approximately 100m watts is practical and attractive since this will enable subscriber transceiver equipment to achieve small form factors that can be integrated into available portable computer equipment.

In conclusion all the major system components and possible operational scenarios have been summarized, and it is SFA's opinion that the proposed system is feasible "as proposed" by PageMart. Therefore we believe the system can be designed to meet its intended purpose.

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